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Barriers to renewable/sustainable energy technologies adoption: Indian perspective

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ABSTRACT

Rapidly increasing energy demand and growing concern about economic and environmental consequences call for renewable/sustainable energy technologies' adoption in India. Renewable/sustainable energy technologies have faced a number of constraints that have affected their rate of adoption. In this paper an attempt has been made to identify and rank the major barriers in the adoption of 'renewable and green' energy technologies in the Indian context. Twenty-eight barriers have been identified from an extensive literature review. These identified barriers have been categorized into seven dimensions of barriers, i.e. Economical & Financial; Market; Awareness & Information; Technical; Ecological and Geographical; Cultural & Behavioral; and Political & Government Issues. Analytical Hierarchy Process (AHP) technique has been utilized for ranking of barriers to adopt renewable/sustainable technologies in the Indian context. All pair comparisons in AHP have been made based on experts' opinions (selected from academia and industry). Sensitivity analysis has also been made to investigate the priority ranking stability of barriers to adopt renewable/sustainable technologies in the Indian context. This paper may help practitioners, regulators and academician focus their future efforts in adoption of 'renewable/sustainable energy technologies' in India. Further, this understanding may be helpful in framing the policies and strategies towards adoption of renewable/sustainable energy technologies.

Contents

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1. Introduction

Due to the rapid consumption of conventional energy resources such as crude oil, coal, and natural gas, many initiatives taken all over the world have addressed towards the efficient use or replacement of these resources. Several renewable energy sources have been introduced and argued as alternatives to traditional sources to protect environmental resources and improve the quality of life. With the growing concerns about Green House Gas (GHG) emissions and consequent climate change, renewable energy sources have become more attractive options for power generation around the world as well as in India.

India accounts for 17% of the world's population but only 4% of the world's primary energy consumption. Modern renewable resources account for a small portion of the total energy mix. India is the only country in the world that has a separate ministry – 'Ministry of New and Renewable Energy' (MNRE), earlier known as the Ministry of Non-Conventional Energy Sources [1].

India has tremendous energy needs and increasing difficulty in meeting those needs through traditional means of power generation. On July 30 and 31, 2012, the world's largest blackout – The Great Indian Outage, stretching from New Delhi to Kolkata – occurred due to the failure of the northern power grid and affected nearly 700 million people (twice the population of the United States) [2]. Renewable energy sources such as small hydropower, wind, solar, biomass, and geothermal may in principle meet many times the world's energy demand; and provide sustainable energy services, based on the use of routinely available, indigenous resources [3].

Renewable energy has the potential to play an important role in providing energy with sustainability to the vast populations in developing countries who as yet have practically no access to clean energy [4]. High population and subsequent increase in energy demand in developing countries highlight and emphasize the urgent need for renewable, sustainable, affordable and environmentally sound energy systems [5]. India is generously endowed with renewable energy sources widely distributed across the country and the overall potential is more than the current total energy consumption [6]. In the context of the global warming and climate change problem, there is an urgent need for India to plan and expedite implementation of strategies for augmenting the renewable energy share in the energy mix [1] for economic and environmental reasons; and India needs to shift to non-polluting renewable sources of energy to meet future demand for electricity justifying investment in this sector of renewable energy as the most attractive because it may provide long-term economic growth for India [2]. Despite technological developments and economic viability for several applications, renewable energy has been used to a small fraction of its potential due to the existence of several types of barriers to adoption of renewable or green energy technologies varying across countries [4]. Therefore, it calls for the need to identify major barriers to the adoption of renewable or sustainable energy technologies in the Indian context. The two main objectives of this paper are to:

- identify various barriers to adoption of renewable or sustainable energy technologies in the Indian context and
- rank identified barriers to the adoption of renewable or sustainable energy technologies in the Indian context.

We have identified Analytic Hierarchy Process (AHP) as an appropriate methodology to rank various barriers to the adoption

of renewable or sustainable energy technologies in the Indian context. AHP, as a decision support tool, uses a multilevel hierarchical structure of objectives, criteria, sub-criteria and alternatives. It works as a multi-attribute decision-making methodology which was first developed and applied by Saaty in 1977 and compares criteria, or alternatives with respect to a criterion, in a natural, pair-wise mode [7–10]. The resultant can be used to compare and rank the alternatives and, hence, assist the decision-making process in making a choice among various alternatives [11,12].

This paper is organized as follows: the next section covers the state-of-the-art status of renewable/sustainable energies in India; thereafter, twenty-eight barriers to renewable/sustainable energy technologies' adoption identified are then categorized into seven representative dimensions based upon their nature in the adoption of renewable/sustainable energy technologies; the research framework and methodology is explained in the next section; thereafter, the data is analyzed and results are then presented; in the last sections, discussions of research findings with the concluding remarks are presented, followed by limitations of the study and future research directions.

2. Renewable/sustainable energy in India

Renewable energy is energy that comes from resources which are continually replenished by nature such as sunlight, wind, rain, geothermal heat, biomass, waves and tides [13], whereas sustainable energy is the sustainable provision of energy that meets the needs of the present without compromising with the ability of future generations [14]. Seven renewable/sustainable energies (solar energy, wind energy, hydro energy, geothermal energy, biomass energy, tidal power and wave energy) have been identified from the literature and explained with their current status in India in brief as follows.

2.1. Solar energy

Solar energy is the prime free source of inexhaustible energy available to all. India is one of the best recipients of solar energy due to its favorable location in the solar belt (40°S to 40°N) [15]. The solar energy potential in India is immense due to its convenient location near the Equator. India receives nearly 3000 h of sunshine every year, which is equivalent to 5000 trillion kWh of energy [16]. By January 2014 the installed grid connected solar power had increased to 2208.36 MW [17], and India expects to install a total of 20,000 MW by 2022 [18]. Developing renewable energy may help India to: increase its energy security; reduce the adverse impacts on the local environment; lower its carbon intensity; contribute to more balanced regional development; and realize its aspirations for leadership in high-technology industries [19].

2.2. Wind energy

Wind energy, commonly recognized to be a clean and environmentally friendly renewable energy resource, may reduce our dependency on fossil fuels [20]. India occupies the fifth place in the world in wind energy generation after USA, Germany, Spain, and China, and has an installed capacity of more than 21136.3 MW as of March 31, 2014 [21]. New technological developments in wind energy design have contributed to the significant advances in wind energy penetration and to obtain optimum power from available wind [22]. India is a prevailing market for the wind industry and the Indian wind sector represents annual growth in 2.1 GW of new installations. The global wind markets grew by an average 28% per year in terms of total installed capacity during the last decade [18].

2.3. Hydro energy

Hydropower is a renewable energy source because it uses the earth's 'natural water cycle' to generate electricity. India has been blessed with an immense amount of hydro-electric potential and ranked fifth in terms of exploitable hydro-potential on global scenario [23]. However, the total hydro-potential in the country is estimated at 150,000 MW [24]; the present installed capacity as on September 30, 2013 is approximately 39,788.40 MW, which is only 17.39% of the total electricity generation in India [25]. Still India has the scope to install hydro-power capacity more than 0.1 million MW. Mini- and micro-hydro-power generation may be good choices on small rivers and canals towards utilization of all existing water reservoirs and streams to generate electricity from hydro-power renewable in nature [26].

2.4. Geothermal energy

Geothermal energy may be used effectively in both on- and off-grid developments, and is especially useful in rural electrification schemes and direct applications like space heating, cooking, bathing and swimming, industrial process heat, agricultural drying, greenhouse and open ground heating, etc. The geothermal resources have been mapped and the Geological Survey of India estimates the potential to be of the order of 10,600 MW [27]. Most of the current usage of geothermal energy is for direct use for bathing and swimming. It is expected that the geothermal sources can be used for low-grade heating and direct utilization in the food processing industry [1].

2.5. Biomass energy

In the past decade there has been renewed interest in biomass as a renewable energy source worldwide. Biofuel may be broadly defined as solid, liquid, or gas fuel consisting of, or derived from, biomass. Lower costs and higher conversion efficiency are the major reasons for biomass conversion to energy in India [28]. A major criticism often leveled against biomass, particularly against large-scale fuel production, is that it may consume vast swaths of farmland and native habitats, drive up food prices, and result in little reduction in green house gas emissions [29–31].

2.6. Tidal power

India has a long coastline about 7500 km [32] with the estuaries and gulfs where tides are strong enough to move turbines for electrical power generation. There is an estimated potential of about 8000 MW tidal energy in the country. This may include about 7000 MW in the Gulf of Cambay, 1200 MW in the Gulf of Kutch in the State of Gujarat and about 100 MW in the Gangetic Delta in the Sunderbans region in the State of West Bengal [33]. Government of Gujarat has signed a 'memorandum of understanding' in January 2011 for establishing a 250 MW tidal power project in Gulf of Kutch. A Special Purpose Vehicle has been incorporated in May 2011 and Gujarat Power Corporation Ltd. (GPCL) has taken up a 50 MW tidal power project at Mandavi in district Kutch in first phase [34]. The Ministry sanctioned a project for setting up a 3.75 MW demonstration tidal power plant at Durgaduani Creek in Sunderbans, West Bengal, to the West Bengal Renewable Energy Development Agency (WBREDA), Kolkata [19].

Table 1
Brief summary of renewable/sustainable energies in India.

S. N.	Renewable/ sustainable energies in India	Available	Being used	Unused	Future plans
1	Solar energy	700–2100 GW [36]	2.20836 GW [17]	Approx. 698 GW to 2098 GW	Produce 20 GW of solar power by 2022 [18,37]
2	Wind energy	102 GW [22]	21.1363 GW [21]	Approx. 81 GW	Ministry of New and Renewable Energy (MNRE) Projection to install another 20,000 MW by 2022 [19]
3	Hydro energy	150 GW [23,24]	39.788 GW [25]	Approx. 110 GW	A *target* of expanding small *hydro* capacity to 7 GW by the end of the 12th Plan in 2017 [19,38]
4	Geothermal energy	10.6 GW [27]	0 GW	10.6 GW	Chhattisgarh government has decided to establish the first geothermal power plant of the country in the newly formed Balrampur district of the state [39].
5	Biomass energy	23 GW [40]	1.285 GW [19]	21.715 GW	Biodiesel is not sold on the Indian fuel market, but the government plans to meet 20% of the country's diesel requirements by 2020 using biodiesel [40].
6	Tidal power	8 GW [33]	-	8 GW	The Ministry sanctioned a project for setting up of a 3.75 MW demonstration tidal power plant [19].
7	Wave energy	40 GW [34]	0.001 GW (Prototype) [41]	Approx. 40 GW	The Government of Maharashtra and Government of India have plans to announce policies to attract private investors in this field on a BOO (Build Own Operate) basis [34].

2.7. Wave energy

Ocean is one of the sources of renewable energy that may supply part of the world's energy needs and reduce dependency on consumption of fossil fuels and other non-renewable resources [35]. Sea waves are the result of transfer of mechanical energy of wind to wave energy. The wave quality varies for different periods and seasons. It is possible to have a realistic formula to calculate the overall wave energy potential. A general study of the wave nature has shown that there is a potential of 40,000 MW along the Indian coast [34]. However, the realistic and economical potential is likely to be considerably less. However though prototypes have been built and some operating experience obtained, this is not yet a commercially available technology. A wave energy plant installed by National Institute of Ocean Technology (NIOT) currently yields 6–7 kW to produce 7000–8000 l of desalinated water per day [1].

Brief summary of renewable/sustainable energies in India is shown in Table 1.

3. Barriers to renewable/sustainable energy technologies adoption

Several barriers have been listed in the literature. These may include financial barriers, technical barriers, and market barriers such as inconsistent pricing structures; institutional, political and regulatory barriers; and social and environmental barriers. Some barriers may be specific to a technology, while some may be specific to a country or a region. Barriers to adoption of renewable or sustainable energy technologies in the Indian context have been identified through extensive literature review. Literature survey was conducted by searching key words like Renewable/Sustainable energy technologies; Barriers to Renewable/Sustainable energies technologies; Barriers to adopt Renewable/Sustainable energies technologies in India; Renewable/Sustainable energy technologies implementation in India. Science direct; Emerald; Scopus; DOAJ; Google search and Google scholar databases were used. A search criterion was based on books and research papers published in journals and conference proceedings. Important twenty-eight barriers to adopt renewable/sustainable energy technologies were identified from an extensive literature review. The paucity of literature in the Indian context forced us to consider the literature available for other developed/developing countries and assume a somewhat similar scenario for India for identifying the relevant renewable/sustainable energy technologies. These are explained as follows.

3.1. High initial capital cost

Technology imported, from highly industrialized and technologically advanced countries, is more efficient but at the same time it may be more expensive than technology manufactured locally requiring higher initial investment costs [42]. Initial costs for renewable/sustainable energy technologies tend to be high [43] and uncompetitive which may prohibit the consumers from adopting them. Many consumers give more importance to keep the initial cost low rather than minimizing the operating costs [6].

3.2. Lack of financing mechanism

Many of the renewable energy technologies in India are still in the development stage. As in other developing countries, economic and financial issues appeared crucial for the development of renewable/sustainable energy technologies in India. There is a lack of sufficient government incentives schemes or financing mechanisms to promote the adoption of renewable/sustainable energy technologies by businesses and industries [6]. Poor credit availability to the purchase of renewable energy technologies is a major barrier in the adoption of renewable energy technologies [4]. Small and medium scale enterprises (SMEs) above all face 'lack the finances' towards adoption of cleaner technologies, but may contact with larger technology manufacturers and formal information channels [44,45].

3.3. Transmission and distribution losses

Nearly ninety percent of the coal-fired generating units in India are subcritical, with a maximum thermal efficiency of 35–38%. The average thermal efficiency of these plants is below 30% due to the high ash content and low heat content of Indian coal and inefficiencies in management [46]. Great losses (exceeding 30%) have been observed taking place in the generation, transmission, distribution and usage of electricity. These losses need to be appropriately addressed with continuous monitoring to stop common problems like theft of electricity [47]. Most of renewable/sustainable energies availability and transformation (in to

mechanical and/or electrical form) feasibility may depend upon geographical condition; and point of availability/generation may be far away from the point of consumption, leading to high transmission and distribution losses.

3.4. Inefficient technology

India's coal-fired, oil-fired and natural gas-fired thermal power plants are inefficient, and compared to the average emissions from coal-fired, oil-fired and natural gas-fired thermal power plants in European Union (EU-27) countries, India's thermal power plants emit 50–120% more CO_2 per kWh produced [47]. Inefficient technology or technical risk means a technology underperforms or becomes obsolete prematurely. There may be site-specific reasons which make it a technical risk that will provide a rational reason for rejection [4,6]. Technologies such as concentrating solar power, wind power and numerous other technologies are still in the developmental phase. Renewable technologies currently are at a cost disadvantage when compared with incumbent technologies, such as coal-fired generation [48]. Lack of proven reliability for the technology in India is the barrier to adoption of these advanced technologies [46]. Development efforts on some important technologies have not yet been initiated in India; these include cellulosic ethanol and hot dry rock geothermal resources. The Indian renewable energy program is also characterized by notable lack of promotion and interest in certain promising technologies, e.g. BIGCC and cofiring [49].

3.5. Lack of subsidies

Some states and countries have subsidized renewable energy through production payments or rebates. Rebates are refunds of a specific share of the cost of a technology, or share of total installation costs (for example, 30% of total costs), or refunds of a certain amount of money per unit of capacity installed [50]. Increased access to financial incentives of different forms (subsidy, tax exemption, low interest loan, long-term credit, specific funds for grid connected projects in rural/mountainous areas, etc.) may potentially improve the financial viability of businesses and affordability of services for renewable energy projects [51].

3.6. Lack of consumer awareness to technology

Market imperfection is the most important barrier, indicating relatively poor access to information compared to the conventional energy technologies. Newspapers and magazines were the primary source of their information. Lack of adequate awareness about costs and benefits of the renewable/sustainable energy technologies among stakeholders may result in a lack of interest and commitment to promote them [6]. Large population of the consumers of electricity in India lack easy access to information on the latest technologies, which results in uncertainty about the quality of new and efficient products and technologies of renewable/sustainable energy technologies [52,53].

3.7. Lack of sufficient market base

Renewable energy projects and companies are generally small. Thus they have fewer resources than large generation companies or integrated utilities. These small companies are less able to communicate directly with large numbers of customers. They will have less clout negotiating favorable terms with larger market players. And they are less able to participate in regulatory or legislative proceedings, or in industry forums defining new electricity market rules [54]. In India, the size of sustainable electricity market is not big enough. Due to lack of sufficient market base, private investment is discouraged [47] and also lack of policies that attract sufficient private investments and development assistance in sustainable energy technologies adoption [55].

3.8. Lack of paying capacity

Renewable/sustainable technologies are primarily targeted at rural areas or poor customers, who have limited capacity to absorb these technologies [4]. High first costs and investments associated with mass manufacturing remain as barriers. Both users and the manufactures have very low capital [56,57]. For developing countries, those technologies (which had not been used in their context before) had been more expensive as well as presented more risk than existing technologies [57]. Unwillingness to pay more money has been attributed to the physical distance from a renewable/sustainable energy projects, low income and an overall low priority given to environmental issues [58].

3.9. Need for backup or storage device

Due to weather conditions and the fact that daylight hours are limited, along with an uneven geographic distribution of solar resources, solar power is intermittent [47]. To supply un-interrupted and continuous power supply, backup or storage devices are required. In addition, disposal of battery (storage device) is a major environmental issue [59].

3.10. Unavailability of solar radiation data

Unavailability of solar radiation data identified as a barrier. Solar energy incident on the earth's surface depends on the geographic location, earth–sun movement, tilts of the earth's rotational axis and atmospheric attenuation due to suspended particles. Accurate solar radiation data, required to establish solar power projects, is not available [60]. It is suggested that India should set up its own solar radiation data collection stations for accelerating development of solar power projects in the country [47].

3.11. Lack of information technology resources

Poor 'information flow and communication' may be one of the greatest barriers to technology transfer experienced in an industry. Information support is necessary for developing linkages to achieve efficient renewable energy technologies. Information technology resources optimize the resources required to support the business and will to reduce paper usage [61]. 'Information Technology and its impact on the technology transfer process implementation' is unquestionably a major concern when managing a technology transfer process [62].

3.12. Lack of awareness of technology

One of the main difficulties encountered is the lack of information and awareness on renewable energy systems and technologies among the rural people [63]. Education and information dissemination related to renewable energy must include everything from resource studies and education about various renewable technologies, to training and information about available government incentives and support systems [50]. Lack of knowledge of technology operation and management as well as limited availability of spare parts and maintenance expertise are the few obstacles to adopting renewable/sustainable energy technologies [64].

3.13. Less efficiency

Renewable energy technologies are often perceived to be used with discomfort or sacrifice rather than as providing equivalent services with less energy and cost [45]. Also, while purchasing a technology, consumers take the advice of their friends rather than obtaining information from experts and take decisions which may not be economically rationale [6].

3.14. Technology complexity

Most of the renewable energy/sustainable technologies are complex in nature. Wind energy is generated by complex mechanisms involving the rotation of the earth, heat energy from the sun, the cooling effects of the oceans and polar ice caps, temperature gradients between land and sea and the physical effects of mountains and other obstacles [65]. Bioenergy production poses a complex multi-phase location/technology/capacity/route analysis problem, optimizing for multiple conflicting objectives, which may lead to sub-optimal solutions that require careful consideration of the tradeoffs among the objectives in order to identify a compromise solution [66].

3.15. Lack of research and development work

Renewable energy technologies in India are still in the development stage [4]. Lack of Research & Development (R&D) work barrier is making adoption of renewable technologies difficult [46,54]. Large investment required for R&D work is one of the major barriers in the adoption of renewable/sustainable energy technologies. R&D often results in benefits that cannot be captured by private entities. Although benefits might accrue to the society at large, individual firms cannot realize the full economic benefits of their R&D investments [67].

3.16. Lack of trained people and training institutes

In India and much of South East Asia, there is a need for technically trained people and people with strong management skills. Where training of local workforce is provided, it should be recognized that Asians tend to learn more effectively by coping, rather than as individuals, when local language is used and with a practical “hands on” approach. Also the issue of training in intellectual property rights is important. This is a long-term issue but will be important for long-term changes in attitudes to intellectual property rights in India [68]. There is a lack of adequate guidance and technical support for operators that prevent the efficient exploitation of renewable/sustainable resources [69].

3.17. Lack of local infrastructure

Infrastructure here broadly refers to not only physical facilities of transmission and distribution networks, but also necessary equipment and services for power companies. There is no clear division of authority between units functioning at the state level and provincial and local authorities when it comes to exploiting and developing renewable resources for electricity production [70]. There are no institutional mechanisms to provide after-sale support to these technologies. Limited private sector participation and target linked programs have not been able to infuse motivation to the existing institutional mechanisms to be able to cater to the new markets [54].

3.18. Lack of national infrastructure

Renewable Energy Technologies such as wind may need strong infrastructure development. Lack of infrastructure is another aspect of institutional barriers, pointed out by [4], that is, problems related to the availability of infrastructure such as roads, connectivity to grid, communications, and other logistics. The regulatory barriers resulted in problems in land acquisition and problems in getting clearances whereas a lack of infrastructure facilities added to the cost [6].

3.19. Scarcity of natural and renewable resources

Unprecedented growth in human population has been observed in India. This growth has been fed by equally unprecedented natural resource consumption and environmental impacts, including conversion of large portions of the natural world to human use, which have prompted recurring concern about whether the world's natural resource base is capable of sustaining such growth [71]. Scarcity of natural resources and increase in price of non-renewable resources will place renewable and recycled resources progressively on the business agenda of industries [72].

3.20. Geographic conditions

Taking into consideration the geographical and weather conditions of India, solar and wind energy are intermittent. For solar energy, daylight hours are limited, along with an uneven geographic distribution of solar resources; solar power is intermittent [47]. The technical potential takes into account geographical restrictions (e.g. land-use cover that reduces the theoretical potential) as well as technical and structural constraints [73].

3.21. Unable to meet electricity power demand alone

The electrical energy demand of India for 2021–2022 is expected to be at least 1915 tera watt hours, with a peak electric demand of 298 GW [74]. If current average transmission and distribution average losses remain the same (32%), India needs to add about 135 GW of power generation capacity, before 2017, to satisfy the projected demand after losses [47]. It is not possible to meet electricity demand with only one source of renewable energy like solar energy, tidal, etc. India needs multiple renewable energy sources [75]. Integration with large renewable/sustainable energy generation systems with smart grids make it so difficult and complex [76].

3.22. Lack of experience

It is generally believed that the adoption of renewable energy technologies is often not undertaken as a result of lack of information/ knowledge or experience on the part of the customer, or lack of confidence in obtaining reliable information [6]. Many potential users of sustainable energy technologies have no or little experience with their application and the assistance provided in the development of such technologies is insufficient [77].

3.23. Rehabilitation controversies

Hydroelectric power projects in India’s mountainous north and northeast regions have been slowed down by ecological, environmental and rehabilitation controversies, coupled with public interest litigations. India’s nuclear power generation potential has been stymied by political activism since the Fukushima disaster in Japan [47]. Any hydro-electric power generation plant

Table 2
Barriers to renewable/sustainable energy technologies adoption.

Dimension s. n.	Dimensions of barriers to adopt renewable/sustainable energy technologies	Barrier s. n.	Barriers to adopt renewable/sustainable energy technologies
1	Economical & Financial (EF)	1.1	High initial capital cost (EF1)
		1.2	Lack of financing mechanism (EF2)
		1.3	Transmission & distribution losses (EF3)
		1.4	Inefficient technology (EF4)
		1.5	Lack of subsidies (EF5)
2	Market (MA)	2.1	Lack of consumer awareness to technology (MA1)
		2.2.	Lack of sufficient market base (MA2)
		2.3	Unable to meet electricity power demand alone (MA3)
		2.4	Lack of paying capacity (MA4)
3	Awareness & Information (AI)	3.1	Need for backup or storage device (AI1)
		3.2	Unavailability of solar radiation data(AI2)
		3.3	Lack of IT enablement (AI3)
4	Technical (TE)	4.1	Lack of awareness of technology (TE1)
		4.2	Less efficiency (TE2)
		4.3	Technology complexity (TE3)
		4.4	Lack of research & development work (TE4)
		4.5	Lack of trained people & training institutes (TE5)
		4.6	Lack of local infrastructure (TE6)
		4.7	Lack of national infrastructure (TE7)
5	Ecological & Geographical (EG)	5.1	Scarcity of natural & renewable resources (EG1)
		5.2	Geographic conditions (EG2)
		5.3	Ecological issues (EG3)
6	Cultural & Behavioral (CB)	6.1	Lack of experience (CB1)
		6.2	Rehabilitation controversies (CB2)
		6.3	Faith & Beliefs (CB3)
7	Political & Government Issues (PG)	7.1	Lack of political commitment (PG1)
		7.2	Lack of adequate government policies (PG2)
		7.3	Lack of public interest litigations (PG3)

Table 3
Random index [11].

N	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

is a challenge on multiple fronts, e.g. engineering, ecological, environmental, social science and economic. Apart from power generation, a proper designed dam can increase the shipping capacity of the river; reduce the potential for floods downstream by providing flood storage space, and serve irrigation and other needs for water [78].

3.24. Faith and beliefs

There is a general resistance to change, which is magnified due to lack of capacity to understand, adopt and adapt the technologies for greater benefit [70]. Equipment manufacturers may be unable or unwilling to provide information because they would be unable to capture all the benefits [6].

3.25. Lack of political commitment

In theory, India is endowed with economically exploitable and viable hydro-potential assessed to be about 1, 48, 700 MW at 60% load factor [79]. This potential cannot be exploited without clear political vision with efficient scientific and technological support [78]. Nuclear energy is not simply a technical or financial issue as it is more about political and strategic stability of a particular state. For India it has been intensely a political issue as well as a strategic challenge [80]. Political instability, government intervention in domestic markets, corruption and lack of civil society are major barriers in renewable/sustainable technologies adoption [67].

3.26. Lack of adequate government policies

Most of the renewable energy technologies in India are still in the development stage. There are no comprehensive policy statements for renewable energy in a country like India. Policies have been issued as and when necessary to facilitate the growth of specific renewable energy technologies. Further, the plans for development of renewable energy do not match up to these policies [18]. Yang (2006) reviewed industrial energy efficiency policies in India from 1980 to 2005. Six major policies were implemented during this period: (1) disclosure of company-level energy efficiency information; (2) accelerated depreciation for energy efficiency and pollution control equipment; (3) establishment of the Energy Management Center under the Ministry of Energy; (4) removal of price and output controls to promote industrial competitiveness; (5) energy price reforms to guide energy efficiency initiatives and encourage international competitiveness; and (6) passage of the Energy Conservation Act of 2001 and the Electricity Act of 2003 [81]. The Energy Conservation Act resulted in the creation of the Bureau of Energy Efficiency (BEE), a statutory body under the Ministry of Power. BEE actively promotes, manages, finances, and monitors energy conservation efforts in the economy through energy audits. It also has the statutory authority to implement mandatory energy efficiency standards but has not yet done so [46].

3.27. Lack of public interest litigations

There is a lack of public interest litigations to promote renewable/sustainable energy technologies adoption. Governments can provide information about energy efficiency by requiring that appliances and machinery be labeled to show their energy usage and that efficiency claims be certified. This is beginning to be done in India, through the Bureau of Energy Efficiency, but some labeling programs are still not mandatory [46]. Lack of public

interest litigations is one of the barriers identified for promoting renewable/sustainable energy technologies in India [82].

3.28. Ecological issues

The environmental costs of fossil, hydroelectric and nuclear energy consumption could drive the world towards alternative sources before scarcity becomes a significant issue. The associated ecological and environmental problems with a dam can be solved easily with proper aforestation, and the social problems can be addressed by sensitive, democratic and participatory rehabilitation policies [78]. In wind power, sound and visual impact are the two main public health and community concerns [83]. The potential environmental impacts associated with solar power are land use and habitat loss, water use and the use of hazardous materials in manufacturing [84].

Further, for validation of the identified barriers to adopt renewable/sustainable energy technologies have been carried out the experts from academia and industry. A workshop was conducted in which experts (four from academia and four from industry) were invited for a brainstorming session to seek their opinion on how important a role the barriers play in hindering the implementation of renewable energy technologies in the Indian context. Barriers identified through extensive literature review were validated through discussions with experts (academia and senior/middle-level engineers/managers) and twenty-eight barriers have been categorized into seven dimensions based upon their nature in adoption of renewable/sustainable energy technologies, i.e. Economical & Financial, Market, Awareness & Information, Technical, Ecological & Geographical, Cultural & Behavioral and Political & Government Issues. These identified barriers to adopt renewable/sustainable energy technologies are shown in Table 2.

4. Methodology

Barriers to adopt renewable/sustainable energy technologies ranking problem in the Indian context has been dealt with the Analytic hierarchy process. Sensitivity analysis has also been applied to examine the robustness of the preferences given by the decision makers in adapted AHP methodology.

4.1. Analytical hierarchy process: step-wise procedure

The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pair-wise mode. The resultant can be used to compare and rank the alternatives and, hence, assist the decision maker in making a choice. AHP has the following steps [7–11]:

Step 1: Establishing the hierarchical structure. Experts are requested to make pair-wise comparisons between barriers and dimensions using a nine-point scale.
Twenty-eight barriers to adopt renewable/sustainable energy technologies have been identified from an extensive literature review, validated and categorized into seven dimensions based on their nature through discussions with experts. These identified barrier dimensions and barriers have been converted into hierarchical-level processes, which include four levels:

Level 1: Goal (Analysis of barriers to adopt renewable/sustainable energy technologies in the Indian context).
Level 2: Represents the priority of the identified seven dimensions of barriers.
Level 3: The hierarchy contains priority of barriers within dimension.
Level 4: Contains overall ranking or priorities of barriers renewable/sustainable energy technologies in the Indian context.

Step 2: Constructing the pair-wise comparison matrix. Construct a set of pair-wise comparison matrices.
These pair-wise comparisons of dimensions and barriers have been converted into comparison matrices. These comparison matrices have been solved with the AHP methodology to determine priority matrices. Global priority weights are associated with dimensions and local weights are associated with barriers within the specific dimension [85].

Step 3: Calculating the consistency
To ensure that the priority of elements is consistent, the maximum eigenvector or relative weights are calculated. Then, compute the consistency index (**CI**) for each matrix order **n** using Eq. (1). Based on the **CI** and Random Consistency index (**RI**), the consistency ratio (**CR**) is calculated using Eq. (2). The **CI** and **CR** are defined as follows [11]:

$$\mathbf{CI} = (\boldsymbol{\lambda}\ \max\ - \mathbf{n})/(\mathbf{n} - \mathbf{1})\ldots\ldots \tag{1}$$

The consistency ratio is then calculated using the formulae

$$\mathbf{CR} = \mathbf{CI}/\mathbf{RI} \tag{2}$$

where **RI** varies depending upon the order of matrix. Table 3 shows the value of the **RI** for matrices of order (N) 1–10 obtained by approximating random indices using a sample size of 500 [11].

The acceptable **CR** range varies according to the size of the matrix, i.e. 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix and 0.1 for all larger matrices, $\mathbf{n} >= 5$ [11,12]. If the value of **CR** is equal to or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if **CR** is more than the acceptable value, inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered and improved. An acceptable consistency ratio helps ensure decision maker's reliability in determining the priorities of a set of criteria [85,86].

4.2. Sensitivity analysis

Normally, data in Multi-Criteria Decision Making (MCDM) problems are imprecise and changeable. Sensitivity analysis can be helpful in model verification. Model verification is a process of making sure that the model is doing what it is intended to do [87]. Sensitivity analysis approach determines the smallest change in the current weights of the criteria, which can alter the existing ranking of the alternatives. The decision maker can make better decisions if he/she can determine how critical each criterion is or how sensitive the actual ranking of the alternatives is to changes on the current weights of the decision criteria [88]. Govindan et al. [89] suggested that small changes in relative weights would provide major changes in the final ranking of variables. These relative weights are usually based on highly individual judgments and, therefore, ranking stability under varying barrier category or dimension weights should be tested [89].

5. Data analysis and results

Based on the ratings obtained through the questionnaire by experts during workshop, matrices are formed and the priorities are synthesized using the methodology of AHP.

5.1. AHP results

AHP framework of barriers to adopt renewable/sustainable energy technologies in the Indian context ranking problem is structured as a hierarchy that includes four levels as discussed in methodology section. Goal (level 1) of this research is to analyze barriers to adopt renewable/sustainable energy technologies in the Indian context.

5.1.1. Constructing the hierarchy of dimensions to renewable/sustainable energy technologies adoption: level 2

Seven categorized dimensions (Economical & Financial, Market, Awareness & Information, Technical, Ecological & Geographical, Cultural & Behavioral and Political & Government Issues) have been checked for hierarchy. Table 4 shows the weights given by experts to these dimensions and priority matrix.

From the analytical results shown in Table 4, 'Ecological & Geographical (0.303)' has been reported as the most important dimension of barriers to adopt renewable/sustainable energy technologies, followed by 'Political & Government Issues (0.267)'; 'Technical (0.152)'; 'Economical & Financial (0.127)'; 'Awareness & Information (0.080)'; 'Cultural & Behavioral (0.038)'; and 'Awareness & Information (0.033)'.

5.1.2. Constructing the hierarchy of barriers to adopt renewable/sustainable energy technologies adoption: level 3

In the 3rd level, barriers in each dimension have been rated by experts and checked for hierarchy. The maximum eigenvalues, C.I. and pair-wise comparison matrix of each barrier are shown in Table 5 as follows.

Table 5 shows that 'High initial capital cost (0.286)' has been found as the most important barrier in "Economical & Financial" dimension of barriers to adopt renewable/sustainable energy technologies, followed by 'Lack of financing mechanism (0.217)'; 'Inefficient technology (0.187)'; 'Transmission & distribution losses (0.159)' and 'Lack of Subsidies (0.151)'.

Similarly, dimension 2 to dimension 7 of barriers to adopt renewable/sustainable energy technologies (Tables 6–11) have been ranked, respectively.

Table 6 shows that 'Lack of consumer awareness to technology (0.330)' and 'Lack of sufficient market base (0.330)' have been found as the most important barriers in "Market" dimension of barriers to adopt renewable/sustainable energy technologies, followed by 'Lack of paying capacity (0.200)' and 'Unable to meet electricity power demand alone (0.140)'.

'Unavailability of solar radiation data (0.413)' has been reported as the most important barrier in "Awareness & Information" dimension of barriers to adopt renewable/sustainable energy technologies, followed by 'Lack of IT enablement (0.327)' and 'Need for backup or storage device (0.260)' as shown in Table 7.

From the analytical results shown in Table 8, 'Technology complexity (0.241)' has been reported as the most important barrier in "Technical" dimension of barriers to adopt renewable/sustainable energy technologies followed by 'Less efficiency (0.181)'; 'Lack of national infrastructure (0.164)'; 'Lack of R & D work (0.149)'; 'Lack of local infrastructure (0.122)'; Lack of trained

Table 5
Ranking of barriers in "Dimension 1: Economical & Financial" to adopt renewable/sustainable energy technologies adoption.

Economical & Financial barriers	EF1	EF2	EF3	EF4	EF5	Local priority weighting	Rank
EF1	1.000	2.000	3.000	1.000	1.000	0.286	1st
FF2	0.500	1.000	2.000	1.000	2.000	0.217	2nd
FF3	0.333	0.500	1.000	1.000	2.000	0.159	4th
EF4	1.000	1.000	1.000	1.000	1.000	0.187	3rd
EF5	1.000	0.500	0.500	1.000	1.000	0.151	5th

Maximum Eigenvalue = 5.36575.
C.I. = 0.0914371.
Pair-wise comparison matrix of barriers in "Economical & Financial" dimension.

Table 6
Ranking of barriers in "Dimension 2: Market" to adopt renewable/sustainable energy technologies adoption.

Market barriers	MA1	MA2	MA3	MA4	Local priority weighting	Rank
MA1	1.000	1.000	2.000	2.000	0.330	1st
MA2	1.000	1.000	2.000	2.000	0.330	1st
MA3	0.500	0.500	1.000	0.500	0.140	3rd
MA4	0.500	0.500	2.000	1.000	0.200	2nd

Maximum Eigenvalue = 4.06065.
C.I. = 0.0202157.
Pair-wise comparison matrix of barriers in "Market" dimension

Table 7
Ranking of barriers in "Dimension 3: Awareness & Information" to adopt renewable/sustainable energy technologies adoption.

Awareness & Information barriers	AI1	AI2	AI3	Local priority weighting	Rank
AI1	1.000	0.500	1.000	0.260	3rd
AI2	2.000	1.000	1.000	0.413	1st
AI3	1.000	1.000	1.000	0.327	2nd

Maximum Eigenvalue = 3.05362.
C.I. = 0.0268108.
Pair-wise comparison matrix of barriers in "Awareness & Information" dimension.

Table 4
Ranking of dimensions to renewable/sustainable energy technologies adoption.

Barrier dimension category	EF	MA	AI	TE	EG	CB	PG	Global priority weighting	Rank
EF	1.000	3.000	2.000	1.000	0.200	3.000	1.000	0.127	4th
MA	0.333	1.000	0.250	0.250	0.143	1.000	0.143	0.033	7th
AI	0.500	4.000	1.000	1.000	0.143	3.000	0.111	0.080	5th
TE	1.000	4.000	1.000	1.000	1.000	3.000	1.000	0.152	3rd
EG	5.000	7.000	7.000	1.000	1.000	5.000	1.000	0.303	1st
CB	0.333	1.000	0.333	0.333	0.200	1.000	0.143	0.038	6th
PG	1.000	7.000	9.000	1.000	1.000	7.000	1.000	0.267	2nd

Maximum Eigenvalue = 7.69519.
C.I. = 0.115864.
Pair-wise comparison matrix of dimensions of barriers to adopt renewable/sustainable energy technologies.

Table 8
Ranking of barriers in "Dimension 4: Technical" to adopt renewable/sustainable energy technologies adoption.

Technical barriers	TE1	TE2	TE3	TE4	TE5	TE6	TE7	Local priority weighting	Rank
TE1	1.000	0.167	0.167	0.167	0.500	0.333	0.333	0.039	7th
TE2	6.000	1.000	1.000	1.000	2.000	1.000	1.000	0.181	2nd
TE3	6.000	1.000	1.000	2.000	2.000	2.000	2.000	0.241	1st
TE4	6.000	1.000	0.500	1.000	1.000	1.000	1.000	0.149	4th
TE5	2.000	0.500	0.500	1.000	1.000	1.000	0.500	0.104	6th
TE6	3.000	1.000	0.500	1.000	1.000	1.000	0.500	0.122	5th
TE7	3.000	1.000	0.500	1.000	2.000	2.000	1.000	0.164	3rd

Maximum Eigenvalue = 7.19534.
C.I. = 0.0325571.
Pair-wise comparison matrix of barriers in "Technical" dimension.

Table 9
Ranking of barriers in "Dimension 5: Ecological & Geographical" to adopt renewable/sustainable energy technologies adoption.

Ecological & Geographical barriers	EG1	EG2	EG3	Local priority weighting	Rank
EG1	1	2	1	0.387	2nd
EG2	0.5	1	0.333	0.169	3rd
EG3	1	3	1	0.444	1st

Maximum Eigenvalue = 3.01829; C.I. = 0.00914735.
Pair-wise comparison matrix of barriers of "Ecological & Geographical" dimension.

Table 10
Ranking of barriers of "Dimension 6: Cultural & Behavioral" to adopt renewable/sustainable energy technologies adoption.

Cultural & Behavioral barriers	CB1	CB2	CB3	Local priority weighting	Rank
CB1	1.000	0.333	0.500	0.163	3rd
CB2	3.000	1.000	2.000	0.540	1st
CB3	2.000	0.500	1.000	0.297	2nd

Maximum Eigenvalue = 3.0092.
C.I. = 0.00460136.
Pair-wise comparison matrix of barriers in "Cultural & Behavioral" dimension.

Table 11
Ranking of barriers in "Dimension 7: Political & Government Issues" to adopt renewable/sustainable energy technologies adoption.

Political & Government Issues barriers	PG1	PG2	PG3	Local Priority Weighting	Rank
PG1	1.000	2.000	3.000	0.527	1st
PG2	0.500	1.000	3.000	0.333	2nd
PG3	0.333	0.333	1.000	0.140	3rd

Maximum Eigenvalue = 3.05362.
C.I. = 0.0268108.
Pair-wise comparison matrix of ranking of barriers in "Political & Government Issues" dimension.

people & training institutes (0.104)'; and 'Lack of awareness of technology (0.039)'.

'Ecological issues (0.444)' has been reported as the most important barrier in "Ecological & Geographical" dimension of barriers to adopt renewable/sustainable energy technologies, followed by 'Scarcity of natural & renewable resources (0.387)' and 'Geographic conditions (0.169)' as shown in Table 9.

From the analytical results shown in Table 10, 'Rehabilitation controversies (0.540)' has been reported as the most important barrier in "Cultural & Behavioral" dimension of barriers to adopt renewable/sustainable energy technologies followed by 'Faith & Beliefs (0.297)' and 'Lack of experience (0.163)'.

From the analytical results shown in Table 11, 'Lack of political commitment (0.527)' has been reported as the most important barrier in "Political & Government Issues" dimension of barriers to adopt renewable/sustainable energy technologies followed by 'Lack of adequate government policies (0.333)' and 'Lack of public interest litigations (0.140)'.

Consistency ratio (C.R.) values are well in the acceptable range for matrices shown in Tables 3–11, which ensures the decision maker's reliability.

5.1.3. Constructing the overall hierarchy of barriers to renewable/sustainable energy technologies adoption: level 4

Overall weights of barriers have been obtained by multiplying the global weight of dimension of barriers values with the local weights of each specific barrier. Based upon overall weights of barriers, ranking of barriers to adopt renewable/sustainable energy technologies have been made. The priority weighting and ranking of barriers to adopt renewable/sustainable energy technologies have been summarized in Table 12.

5.2. Sensitivity analysis results

As the barriers' importance weights are obtained based on subjective judgments of the functional decision makers, we need to carry out a sensitivity analysis for validation. In this research, "Ecological & Geographical" dimension has reported the highest global weight (Table 4) and thereby influences the other dimensions of barriers to adopt renewable/sustainable energy technologies. Therefore "Ecological & Geographical" dimension has been selected with its value varying from 0.1 to 0.9 with 0.1 as increment and this change has been reflected in the other dimensions of barriers. "Political & Government Issues" dimension of barriers to adopt renewable/sustainable energy technologies shows maximum variation in results. The changes in other dimensions of barriers to adopt renewable/sustainable energy technologies are tabulated in Table 13.

Hence, specific barrier weights and rank also change accordingly. At 0.1 value of "Ecological & Geographical" dimension, barrier PG1 holds the highest value and first rank. Similarly, barrier MA3 holds the lowest value and last rank. Barrier PG1 retains the first rank and barrier MA3 the last rank till the normal

Table 12
The priority weighting and ranking of barriers to adopt renewable/sustainable energy technologies.

Dimension of barriers to adopt renewable/sustainable energy technologies	Global weight of dimension	Rank of Dimension	Barriers to adopt renewable/sustainable energy technologies	Local weight of barriers	Overall weight of barriers	Overall ranking of barriers
Economical & Financial	0.127	4th	High initial capital cost	0.286	0.0363	8th
			Lack of financing mechanism	0.217	0.0276	10th
			Transmission & distribution losses	0.159	0.0202	18th
			Inefficient technology	0.187	0.0237	14th
			Lack of subsidies	0.151	0.0192	19th
Market	0.033	7th	Lack of consumer awareness to technology	0.330	0.0109	23rd
			Lack of sufficient market base	0.330	0.0109	23rd
			Unable to meet electricity power demand alone	0.140	0.0046	27th
			Lack of paying capacity	0.200	0.0066	24th
Awareness & Information	0.080	5th	Need for backup or storage device	0.260	0.0208	16th
			Unavailability of solar radiation data	0.413	0.0330	9th
			Lack of IT enablement	0.327	0.0261	12th
Technical	0.152	3rd	Lack of awareness of technology	0.039	0.0059	26th
			Less efficiency	0.181	0.0275	11th
			Technology complexity	0.241	0.0366	7th
			Lack of R & D work	0.149	0.0226	15th
			Lack of trained people & training institutes	0.104	0.0158	21th
			Lack of local infrastructure	0.122	0.0185	20th
			Lack of national infrastructure	0.164	0.0249	13th
Ecological & Geographical	0.303	1st	Scarcity of natural & renewable resources	0.387	0.117	3rd
			Geographic conditions	0.169	0.0512	5th
			Ecological issues	0.444	0.135	2nd
Cultural & Behavioral	0.038	6th	Lack of experience	0.163	0.0062	25th
			Rehabilitation controversies	0.540	0.0205	17th
			Faith & Beliefs	0.297	0.0113	22th
Political & Government Issues	0.267	2nd	Lack of political commitment	0.527	0.141	1st
			Lack of adequate government policies	0.333	0.0889	4th
			Lack of public interest litigations	0.140	0.0374	6th

Table 13
Global priority values of dimensions of barriers to adopting renewable/sustainable energy technologies by varying values of "Ecological & Geographical" dimension.

Dimension of barriers	Global priority values of dimension of barriers after increasing values of "Ecological & Geographical" dimension (0.1–0.9)									
EF	**0.127**	0.164	0.146	0.127	0.108	0.091	0.073	0.055	0.037	0.019
MA	**0.033**	0.043	0.038	0.033	0.028	0.024	0.019	0.014	0.009	0.004
AI	**0.080**	0.104	0.092	0.081	0.070	0.058	0.046	0.034	0.022	0.012
TE	**0.152**	0.196	0.174	0.153	0.131	0.108	0.087	0.065	0.044	0.022
EG	**0.303**	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
CB	**0.038**	0.049	0.044	0.038	0.033	0.027	0.022	0.016	0.011	0.005
PG	**0.267**	0.345	0.306	0.268	0.230	0.192	0.153	0.115	0.077	0.038
Total	**1.000**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

value (0.303) of "Ecological & Geographical" dimension. From varying the values (0.4–0.9) of "Ecological & Geographical" dimension, barrier EG3 holds the highest value, and the values of other barriers vary. The changes in the values of other barriers to adopt renewable/sustainable energy technologies have been tabulated in Table 14. Changes of specific barrier ranks have also been shown in Table 15.

Priority values and ranks changes have been plotted and shown in Fig. 1. It shows that changes in values and ranks of barriers to adopt renewable/sustainable energy technologies vary according to change in the "Ecological & Geographical" dimension.

Here, it may be inferred that "Ecological & Geographical" dimension has more impact on the renewable/sustainable energy technologies adoption and needs more attention to remove the barriers of this dimension. If the "Ecological & Geographical" dimension is eliminated, there is a high possibility of eliminating the other remaining dimensions of barriers to adopt renewable/sustainable energy technologies. The same elimination procedure may also be helpful in removing specific barriers to adopt renewable/sustainable energy technologies. This framework may be very helpful in eliminating the barriers and adopting renewable/sustainable energy technologies in an effective way without any hurdles.

6. Discussions and conclusion

In the past decade the field of renewable energy technologies worldwide has received considerable attention. Renewable energy has been considered as one of the strong contenders to improve the plight of two billion people, mostly in rural areas, without access to modern forms of energy [90]. India is a country which is very rich in renewable energy sources, viz., solar, wind, biomass and hydro energy. Many of these resources have a great potential

Table 14
Barriers' local priority values when increasing "Ecological & Geographical" dimension value from 0.1 to 0.9 by sensitivity analysis.

Barrier S. N.	Barriers' local priority values in sensitivity analysis by changing "Ecological & Geographical" dimension values from 0.1 to 0.9									
	0.1	0.2	0.3	Normal (0.303)	0.4	0.5	0.6	0.7	0.8	0.9
EF1	0.0469	0.0418	0.0363	0.0363	0.0309	0.0260	0.0209	0.0157	0.0106	0.0054
EF2	0.0356	0.0317	0.0276	0.0276	0.0234	0.0197	0.0158	0.0119	0.0081	0.0041
EF3	0.0261	0.0232	0.0202	0.0202	0.0172	0.0145	0.0116	0.0087	0.0059	0.0030
EF4	0.0307	0.0273	0.0237	0.0237	0.0202	0.0170	0.0137	0.0103	0.0069	0.0036
EF5	0.0248	0.0220	0.0192	0.0192	0.0163	0.0137	0.0110	0.0083	0.0056	0.0029
MA1	0.0142	0.0013	0.0011	0.0109	0.0009	0.0008	0.0006	0.0005	0.0003	0.0001
MA2	0.0142	0.0013	0.0011	0.0109	0.0009	0.0008	0.0006	0.0005	0.0003	0.0001
MA3	0.0060	0.0005	0.0005	0.0046	0.0004	0.0003	0.0003	0.0002	0.0001	0.0001
MA4	0.0086	0.0008	0.0007	0.0066	0.0006	0.0005	0.0004	0.0003	0.0002	0.0001
AI1	0.0270	0.0239	0.0211	0.0208	0.0182	0.0151	0.0120	0.0088	0.0057	0.0031
AI2	0.0430	0.0380	0.0335	0.0330	0.0289	0.0240	0.0190	0.0140	0.0091	0.0050
AI3	0.0340	0.0301	0.0265	0.0261	0.0229	0.0190	0.0150	0.0111	0.0072	0.0039
TE1	0.0076	0.0068	0.0060	0.0059	0.0051	0.0042	0.0034	0.0025	0.0017	0.0009
TE2	0.0354	0.0315	0.0277	0.0275	0.0237	0.0195	0.0157	0.0118	0.0080	0.0040
TE3	0.0471	0.0419	0.0369	0.0366	0.0316	0.0261	0.0210	0.0158	0.0107	0.0055
TE4	0.0292	0.0259	0.0228	0.0226	0.0195	0.0161	0.0130	0.0097	0.0066	0.0033
TE5	0.0204	0.0181	0.0159	0.0158	0.0136	0.0112	0.0090	0.0068	0.0046	0.0023
TE6	0.0239	0.0212	0.0187	0.0185	0.0160	0.0132	0.0106	0.0079	0.0054	0.0027
TE7	0.0321	0.0285	0.0251	0.0249	0.0215	0.0177	0.0143	0.0107	0.0072	0.0037
EG1	0.0387	0.0774	0.1161	0.117	0.1548	0.1935	0.2322	0.2709	0.3096	0.3483
EG2	0.0168	0.0338	0.0507	0.0512	0.0676	0.0845	0.1014	0.1183	0.1352	0.1521
EG3	0.0444	0.0888	0.1332	0.135	0.1776	0.2220	0.2664	0.3108	0.3552	0.3996
CB1	0.0080	0.0072	0.0062	0.0062	0.0054	0.0044	0.0036	0.0026	0.0018	0.0008
CB2	0.0264	0.0238	0.0205	0.0205	0.0178	0.0146	0.0119	0.0086	0.0058	0.0027
CB3	0.0146	0.0131	0.0113	0.0113	0.0098	0.0080	0.0065	0.0048	0.0033	0.0015
PG1	0.1820	0.1613	0.1412	0.141	0.1212	0.1012	0.0806	0.0606	0.0406	0.0200
PG2	0.1150	0.1019	0.0892	0.0889	0.0766	0.0639	0.0509	0.0383	0.0256	0.0127
PG3	0.0483	0.0428	0.0375	0.0374	0.0322	0.0269	0.0214	0.0161	0.0108	0.0053

Table 15
Ranking for barriers when increasing "Ecological & Geographical" dimension value from 0.1 to 0.9 by sensitivity analysis.

Barrier S. N.	Ranking of barriers by changing "Ecological & Geographical" dimension value from 0.1 to 0.9									
	0.1	0.2	0.3	Normal (0.303)	0.4	0.5	0.6	0.7	0.8	0.9
EF1	5	7	8	8	8	8	8	8	8	8
EF2	9	10	11	10	11	10	10	10	10	10
EF3	17	18	18	18	18	18	18	17	17	17
EF4	13	14	14	14	14	14	14	14	14	14
EF5	18	19	19	19	19	19	19	19	19	18
MA1	23	25	25	23	25	25	25	25	25	24
MA2	23	25	25	23	25	25	25	25	25	24
MA3	27	27	27	27	27	27	27	27	27	24
MA4	24	26	26	24	26	26	26	26	26	24
AI1	15	16	16	16	16	16	16	16	16	16
AI2	7	8	9	9	9	9	9	9	9	9
AI3	11	12	12	12	12	12	12	12	12	12
TE1	26	24	24	26	24	24	24	24	24	23
TE2	10	11	10	11	10	11	11	11	11	11
TE3	4	6	7	7	7	7	7	7	7	7
TE4	14	15	15	15	15	15	15	15	15	15
TE5	20	21	21	21	21	21	21	21	21	20
TE6	19	20	20	20	20	20	20	20	20	19
TE7	12	13	13	13	13	13	13	13	13	13
EG1	8	4	3	3	2	2	2	2	2	2
EG2	21	9	5	5	5	4	3	3	3	3
EG3	6	3	2	2	1	1	1	1	1	1
CB1	25	23	23	25	23	23	23	23	23	22
CB2	16	17	17	17	17	17	17	18	18	19
CB3	22	22	22	22	22	22	22	22	22	21
PG1	1	1	1	1	3	3	4	4	4	4
PG2	2	2	4	4	4	5	5	5	5	5
PG3	3	5	6	6	6	6	6	6	6	6

for exploitation in India. These renewable resources may also provide commercially attractive options to meet the specific needs for energy services, particularly in rural areas, create new employment opportunities, and offer opportunities to manufacture much of the equipment locally. However, to achieve this goal, a number of barriers will have to be overcome, partially or completely, to increase the market penetration and acceptance of renewable energy technologies. This paper provides identification and ranking of barriers to adopt renewable/sustainable energy technologies in India. A comprehensive literature review and idea engineering workshop were carried out to identify and rank these barriers. Twenty-eight barriers have been identified from extensive literature review. After a long brain storming session, important twenty-eight identified barriers have been categorized into seven dimensions.

AHP has been used for ranking of barriers to adopt renewable/sustainable energy. "Ecological & Geographical" dimension has been found to be the highest global weighted and "Market" dimension the lowest global weighted. These have been ranked as 1st and 7th, respectively. Ecological & Geographical dimension is one of the most important aspects in today's world. Humans are so busy focusing on their own needs and demands that they forget they are depleting resources and causing damage to the nature.

Further, ranking of various barriers in each dimension has been done:

- 'High initial capital' has been reported as the highest ranked barrier and 'Lack of Subsidies' as the lowest ranked barrier in dimension 1 (Economical & Financial).
- Similarly, 'Lack of consumer awareness to technology' and 'Lack of sufficient market base' have been found as the most important barriers and 'Unable to meet electricity power demand alone' as the least important barrier in dimension 2 (Market).
- In dimension 3 (Awareness & Information), 'Unavailability of solar radiation data' barrier has obtained the highest rank and 'Need for backup or storage device barrier' has obtained the lowest rank.

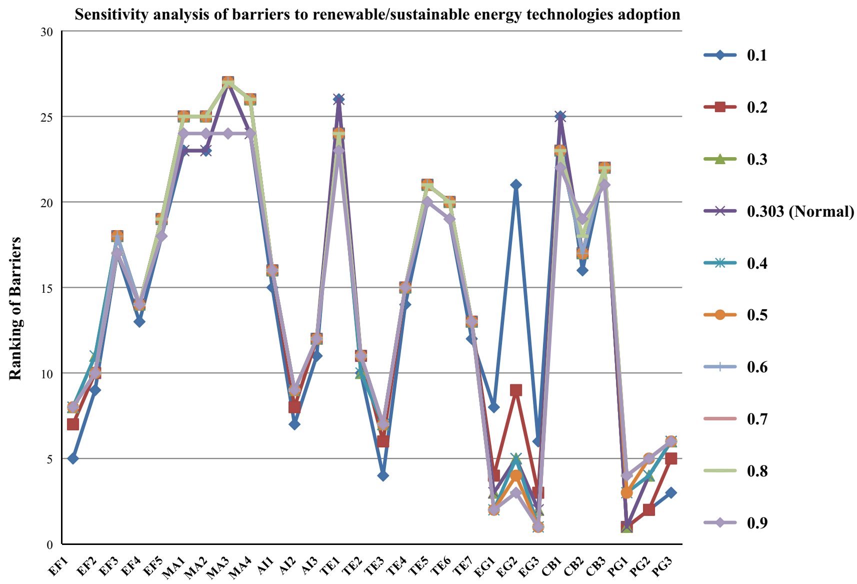

Fig. 1. Sensitivity analysis of barriers to adopt renewable/sustainable energy technologies in the Indian context.

- 'Technology complexity' has been reported as the highest ranked barrier and 'Lack of awareness of technology' as the lowest ranked barrier in dimension 4 (Technical).
- 'Ecological issues' has been reported as the highest ranked barrier and 'Geographic conditions' as the lowest ranked barrier in dimension 5 (Ecological & Geographical).
- 'Rehabilitation controversies' has been reported the most important barrier and 'Lack of experience' as the least important barrier in dimension 6 (Cultural & Behavioral).
- Lack of political commitment' has been reported as the highest ranked barrier and 'Lack of public interest litigations' as the lowest ranked barrier in dimension 7 (Political & Government Issues).

Further, overall ranking of all barriers has also been made by assigning global weights. 'Lack of political commitment'; 'Ecological issues' and 'Scarcity of natural & renewable resources' have been reported as the top three barriers to adopting renewable/sustainable energy technologies in India.

Sensitivity analysis was performed to analyze the changes in the values (0.1 to 0.9) of "Ecological & Geographical" dimension. It gives the changes of rank of specific barriers when the ecological & geographical dimension values change. Dimension of barriers to adopt renewable/sustainable energy technologies in India values are increased from 0.1 to 0.3 with respect to an increase in the "Ecological & Geographical" dimension values, and they decrease when "Ecological & Geographical" dimension values increase from 0.4 to 0.9. This analysis showed that the "Ecological & Geographical" dimension influences and impacts other dimensions of barriers to adopt renewable/sustainable energy technologies.

This paper may play an important role in understanding various barriers, and ranking of these will help in their removal to adopt renewable/sustainable energy technologies in India more effectively and efficiently. This paper has presented a benchmarking framework to make complicated decisions towards the removal of these barriers. Understanding barriers in technology diffusion leads to important lessons in designing policy instruments and institutions for diffusing clean energy technologies in developing countries like India. The proposed framework permits managers/practitioners to make decisions about adopting renewable/sustainable energy technologies in India in the most effective and efficient way.

India may become a potential world leader in the development and deployment of renewable energy technologies and play a significant role in combating global climate change. Renewable energy technologies have a significant positive impact on the environment and the society [91]. This may help managers of renewable energy firms to focus on those areas where they have particular strengths and to introduce measures to overcome potential weaknesses. Governments may come forward to eliminate inappropriate, inconsistent, and inadequate policies that favor conventional fuels and technologies and that fail to recognize the social, environmental, and economic advantages of renewable energy. In the context of global warming, climate change problem and electricity shortage problems, there has been identified an urgent need for India to plan and implement strategies for augmenting the renewable/sustainable energy share in the energy mix. The potential for renewable resources can be realized by promoting innovation and entrepreneurship in renewable resources. Our research has implications for practitioners/managers, policymakers and community stakeholders with an interest in the use of renewable/sustainable energy technologies to solve power problems in developing countries like India. This research has also implications for scholars who may use the framework and propositions to direct new theoretical and empirical analyses to adopt renewable energy technologies.

7. Limitations of the study and scope of future work

We have used AHP for ranking of barriers to adopt renewable/sustainable energy technologies in India. All pair comparisons in AHP have been made on the basis of the experts' opinions (selected from academia and industry). As is natural, opinions of experts may be biased.

From the literature review and expert opinions in detail, various barriers to adopting renewable/sustainable energy technologies in India have been identified and ranked. Different multi-criteria decision-making models may be applied for the same problem and results can be compared in further studies. Real-world case study may be carried out to validate our research work. Further, Interpretive Ranking Process (IRP) may also be applied to rank these barriers with respect to hindering performance measures to adopt renewable/sustainable energy technologies in India.

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